EXPLANATION OF PLATES X. AND XI.

PLATE X.

Fig. 1. *Phalangium cornutum*, body of the female: *a*, side view of the cephalothorax; *b*, part of the cephalothorax and one of the falces of the male.

Fig. 2. *Phalangium urnigerum*, body of the female: *a*, side view of the cephalothorax; *b*, side view of the body with the falces and palpi; *c*, body of the male; *d*, one of the falces.

Fig. 3. *Phalangium parietinum*, body of the female: *a*, side view of the cephalothorax.

Fig. 4. *Megabunus corniger*, body of the male: *a*, eye-eminence seen from above; *b*, side view of the same; *c*, one of the falces of the male; *d*, palpi of male and female.

Fig. 5. *Megabunus insignis*, body of the female: *a*, side view of the eye-eminence; *b*, the same seen from above; *c*, one of the legs; *d*, side view of the body.

PLATE XI.

Fig. 6. *Opilio histrix*, body of the female: *a*, side view of the eye-eminence; *b*, one of the legs; *c*, frontal teeth.

Fig. 7. *Leiobunus rotundus*, body of the female: *a*, body of the male, with one of the palpi attached; *b*, side view of the eye-eminence; *c*, one of the legs; *d*, one of the palpi.

Fig. 8. *Nemastoma chrysomelas*, body of the female: *a*, side view of the body in the male, showing one of the palpi and falces; *b*, eye-eminence or scale; *c*, apex of the abdomen; *d*, one of the falces in the female; *e*, the same in the male.

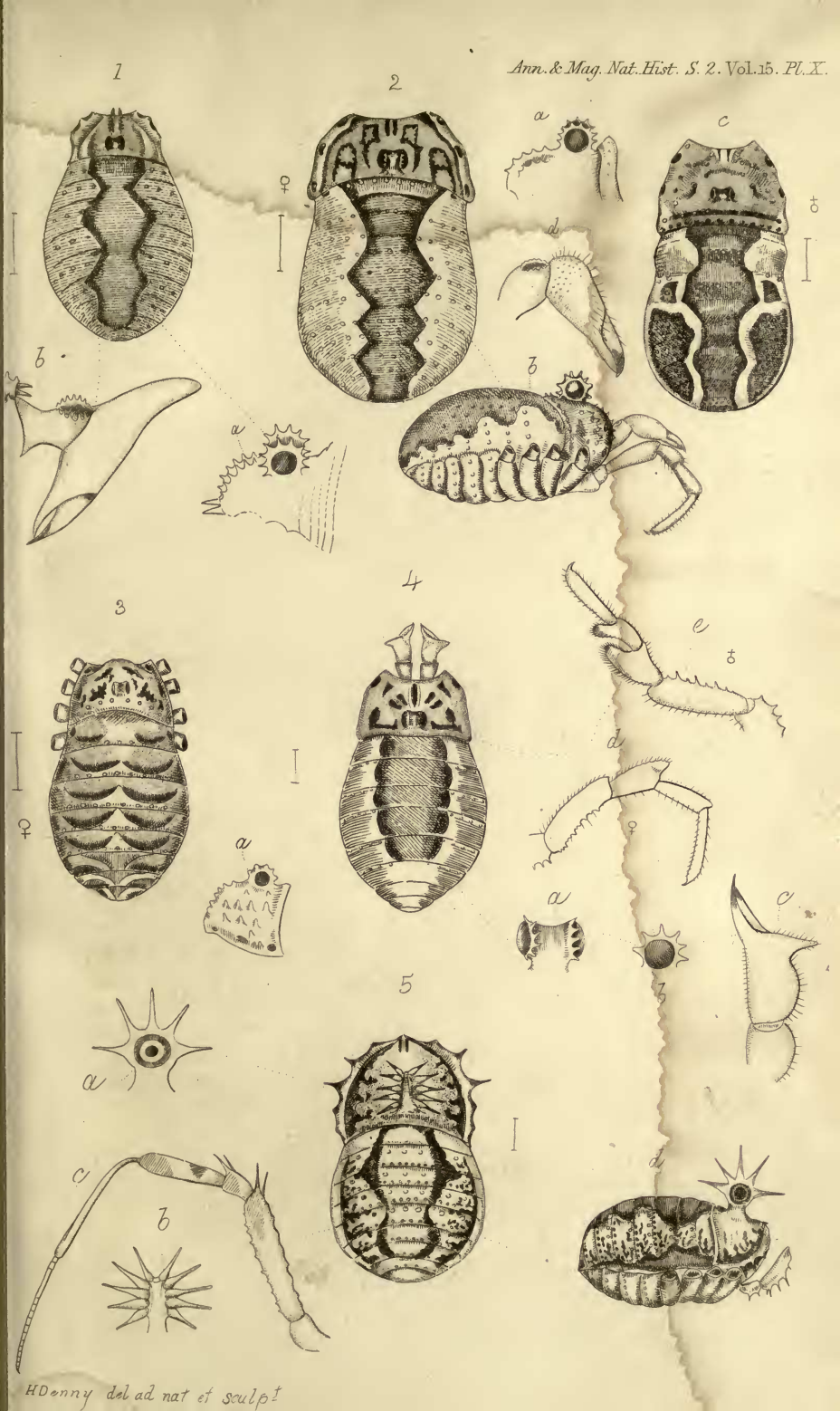
Fig. 9. *Homalenotus quadridentatus*, the body with legs and palpus attached on one side.

XXXVI.—*On the Structure of Chlorophyll.*

By HUGO VON MOHL.

[Concluded from p. 329.]

WITH the pellicular form of the chlorophyll, such as occurs in *Zygnema* (and in still more intimately connected layers in *Draparnaldia*, *Ulothrix*, &c.), as a more or less perfect investment of the cell-wall, is connected in many respects the chlorophyll of *Anthoceros*, for this, in like manner, does not possess the form of isolated grains, but presents itself in every cell as a single chlorophyll-mass, which in a portion of the cells has a membranous form. But the chlorophyll of *Anthoceros* is distinguished from that of *Zygnema*, by the fact that in the latter genus it stands in no direct connexion with the central nucleus, and forms a peripherical layer, while in *Anthoceros* the green colouring matter is connected with one of the masses of protoplasm enveloping the nucleus, and, at least in a portion of the cells, occupies a central position.



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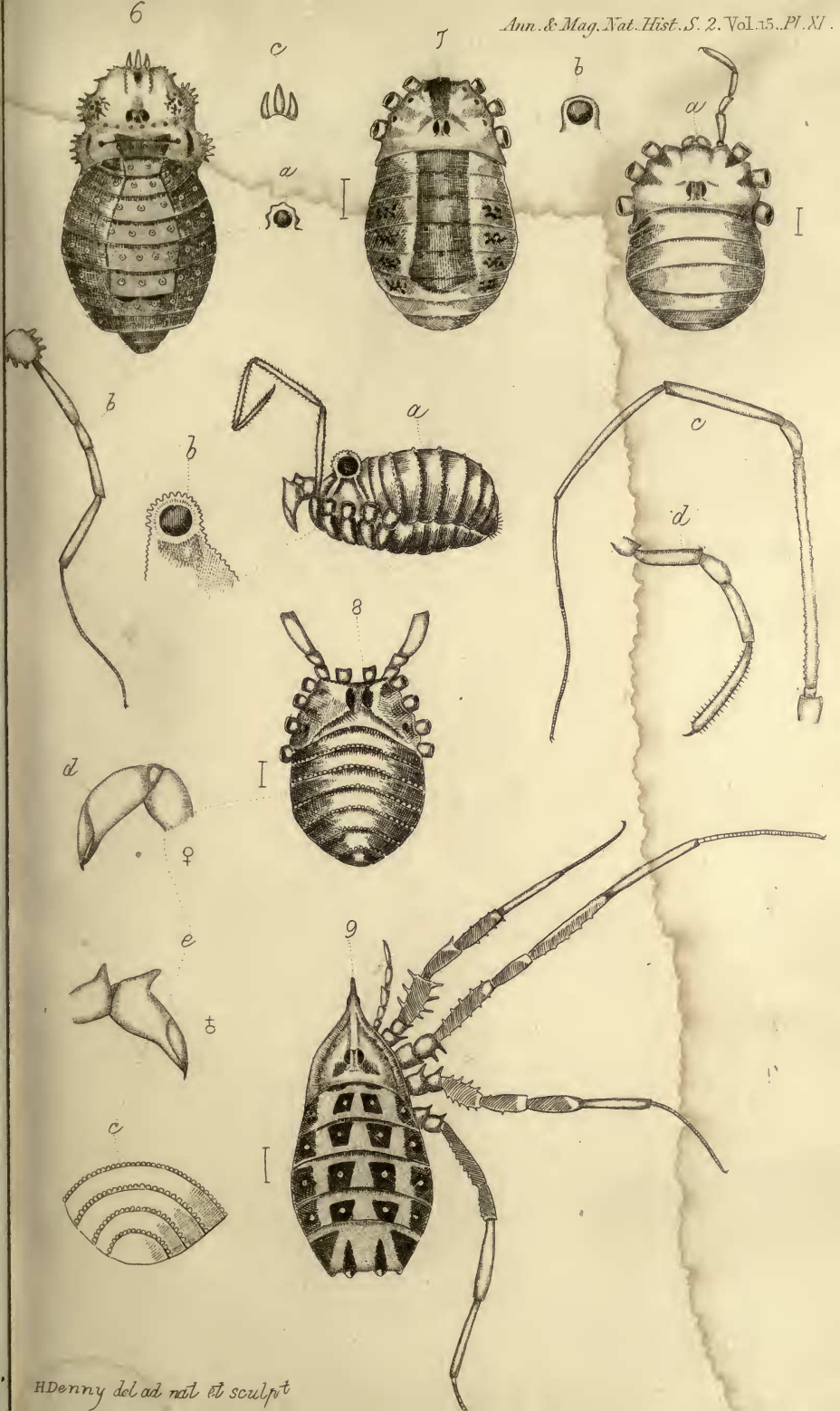

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In all the cells of the frond of *Anthoceros lævis* (with the exception of the epidermal cells), we find a large globular parietal nucleus, within which lie a considerable number (perhaps 100 and more) of small, longish starch-grains. This nucleus is enveloped in a mass of protoplasm, which runs out into two or more short, thick, radiating processes applying themselves to the cell-wall, or has the form of a disk irregularly dentate at the circumference, and corresponds to the lines of circulating protoplasm which in other cells run out from a mass enveloping the nucleus. This entire mass is of a bright green colour, and constitutes the only mass of chlorophyll occurring in the cell.

In the epidermal cells the form of the chlorophyll-mass is somewhat more complicated. Taken as a whole, it has the form of a thin disk stretching across the cell, parallel to the outer wall of the latter, containing in its centre a large globular nucleus, within which lie numerous starch-granules. In young cells, situated near the point of vegetation of the frond, this disk stretches entirely across the cavity of the cell, and its borders are applied upon the side-walls, so that the cell when seen from above appears entirely green. But in the full-grown cell the margin of this green disk has separated at from four to six places from the wall of the cell, become retracted and at the same time turned up towards the outer wall of the cell; so that the disk has now assumed the form of a star-shaped membrane, with from four to six broad rays separated from each other by roundish sinuses, and excavated into the form of gutters on the upper side; the nucleus lies in the centre of this membrane, projecting strongly into the interior of the cell.

It is evident that in this plant the mass of protoplasm, which envelopes the nucleus in all plants, acquires a special development, and that the green colouring matter is connected with it. Whether or not the latter permeates the substance of the nucleus I was unable to discover. The protoplasmic mass appeared finely granular; there was no internal movement of its mass corresponding to the rotation of the sap of many cells. There were no starch-grains in the protoplasm, but only in the nucleus. The presence of these starch-granules, and particularly their large number, is a peculiarity of *Anthoceros*, which is also met with in those nuclei which have no chlorophyll in their vicinity, as, for example, in the epidermal cells of the capsule.

The alterations undergone by the chlorophyll of *Anthoceros* through the action of water, correspond entirely to those above described of *Zygnema*. The chlorophyll-mass swells, with a shortening of its radiating processes, into an irregular globular or ovate shape, the starch-granules lying in the nucleus become at the same time more distinctly visible, while in the interior

are formed one, or more rarely two large vesicles, which break through the outer green layer. Sometimes the formation of a single large vesicle is replaced, in a larger or smaller part of the grain, by that of a large number of small vacuoles, so that the substance of the grain is converted into a frothy mass. No trace of an outer membrane can be detected, consequently I cannot regard as appropriate Hofmeister's application of the term chlorophyll-utricle to this peculiar structure (Vergleich. Untersuch. höh. Kryptog. p. 3).

Notwithstanding, therefore, that the anatomical conditions of the chlorophyll of *Anthoceros* differ essentially from those existing in *Zygnema*, the green-coloured masses of the two plants correspond exactly in regard to the character of their substance and their reaction with water. Hence it seems to follow that all that is requisite for the formation of chlorophyll is, that the green colouring matter be formed in a cell and enter into combination with a mass of proteine substance, be the latter what it may; in any case it is evident that there does not exist any definite elementary organ, comparable in its organization to the cell, uniformly distributed throughout all plants possessing chlorophyll, and especially charged with the formation of this substance. The agreement in the properties of the green-coloured substance of two structures so different as the chlorophyll-masses of *Zygnema* and *Anthoceros*, leads readily to the conjecture that these properties, the different behaviour of the outer green, and internal substance to water, depend less upon peculiarities in the organization (for, as above remarked, no trace of definite structure is visible), than upon the deposition of the green colouring matter, of resinous character and combined with wax. The hypothesis is not far-fetched, that we must regard the different behaviour of the outer and inner substance of the chlorophyll-mass, the greater consistence of the former and the violent expansion of the latter in water, as simple consequences of the proteine substance being permeated principally or solely in its outer layers by these foreign substances, insoluble in water;—or, at least, that this difference, if dependent upon an unequal consistence of the different layers of the proteinous foundation of the chlorophyll-mass, is essentially heightened by that circumstance.

If we turn to the usual form in which chlorophyll occurs, to that of isolated grains, we find that the position of the latter in the cells is not always the same. They are never found swimming freely in the cell-sap, but always stand in connexion with the protoplasm contained in the cell. In the great majority of cases they are applied upon the cell-wall; under these circumstances, we may detect by careful observation, if not in all, yet

in most cases, that the globules are imbedded in a mucilaginous, transparent mass, by which they are attached to the internal surface of the primordial utricle, or with which, in particular cases, as in *Vallisneria**, they are carried along in a flowing movement. In most cases no definite relation can be detected between these parietal chlorophyll-globules and the nucleus and the currents of protoplasm issuing from it; in other instances, on the contrary, the connexion is very manifest. For example, in the parenchyma-cells of the stem of the *Selaginellæ*, the chlorophyll-grains lie in moniliform rows in the protoplasm-threads, which creep out over the cell-wall from the parietal nucleus; and in the Potato, if allowed to become green in the light, chlorophyll-grains are formed in the accumulation of protoplasm surrounding the nucleus, and in the threads radiating from this, in the cells devoid of starch-grains which lie beneath the corky layer.

In regard to the structure of the chlorophyll-globules, investigation of a large number of plants enables us to distinguish two varieties, which in their extreme forms exhibit important differences, not however sharply defined, but passing into one another by a multitude of intermediate stages.

One form consists of globular, but ordinarily flattened grains, with one of their flat sides attached to the cell-wall, the diameter not often exceeding $\frac{1}{300}$ to $\frac{1}{250}$ of a line, frequently not attaining this magnitude. When crowded together, their circumference assumes, like that of epidermal cells, a six-sided, but not acute-angled form; as this form is undoubtedly the result of mutual pressure, this existing notwithstanding that the grains are not in immediate contact, it may be fairly concluded, that they are imbedded in a mucilaginous layer not always recognizable by the microscope, the mutual pressure being communicated through this mucilage. We may distinguish in their substance, frequently however not until after the action of water, fine globules attaining a diameter of about $\frac{1}{2000}$ of a line, which sometimes project upon the surface of the grain, so that its circumference is not bounded by a uniformly curved line, but appears irregularly toothed.

Water very quickly exerts a considerable influence upon these globules. As soon as it penetrates through an opening into the

* I may take this opportunity of adding, that in the cells which form the partitions of the air-cavities in the leaves of *Ceratophyllum demersum*, the chlorophyll-granules exhibit a motion like that in *Vallisneria*, but so slow, that in two cases in which I measured it carefully, they only advanced $\frac{1}{21,660}$ and $\frac{1}{24,000}$ of a line in a second. [This circulation may be well seen in the same manner in the cells of the leaves of *Anacharis Alsinastrum*, but it appears to vary much in rapidity according to circumstances.—A. H.]

cavity of the cell, the globules swell into vesicles, their green colour becoming much lighter and the granules lying inside becoming more distinct. When there are many globules in a cell, and hence the vesicles which they form come to press upon each other, in most cases (at least before the application of iodine) all distinct appearance of detail is lost, and the green contents of the cell seem to have become fused together into an amorphous mass; a condition undoubtedly often seen in microscopic investigations, but which has mostly been regarded as a mechanical disturbance of the chlorophyll resulting from pressure with the knife, or as a proof of the existence of amorphous chlorophyll. But when the globules lie at greater distances apart in the cell, or emerge singly into the water, one is enabled to trace more accurately the alterations they undergo from the action of water. These are essentially of the same kind as those above described of the chlorophyll of *Zygnema* and *Anthoceros*. In each grain one or more vacuoles are formed, expanding the green substance, and afterwards breaking through it in the form of colourless vesicles. The green substance sometimes retains its cohesion, and remains hanging as a cup-like cover upon one side of the vesicle, sometimes becomes partially disintegrated, so that separate pieces of it, distinguishable by their colour or their granules, remain attached, isolated, upon the outer surface of the vesicle; whereby it is clearly perceived that the mucilaginous substance in which the vacuole lies, bears the green substance on its surface, and does not form a membrane surrounding the green matter. The substance of these chlorophyll-globules is very soft, so that not unfrequently, when the covering-glass is placed upon the object, some of the globules which have escaped into the water adhere to the glass and become pushed up together into a shapeless mass, which then usually assumes a frothy condition through the formation of many small vacuoles. That the outermost layer of these chlorophyll-globules possesses a firmer consistence is in the highest degree probable, since otherwise a similar adherence of the globules to foreign substances would be more common, and the mutual pressure would unite the globules into a common mass; but no trace can be discovered of a true membrane distinct from the internal substance. In my former treatise, I stated it to be probable that the fine granules lying in the chlorophyll, in which, from their minute size, I could not discover whether or not they were coloured blue by iodine (as is the case with the larger granules of the second form), were in like manner starch-grains; this was an error, as the use of better microscopes has now convinced me; these revealing that the granules are coloured brown by iodine, in which they agree with the granules occurring in the protoplasm.

I may name *Clivia nobilis*, as a plant in the leaves of which this form of chlorophyll-globules is very beautifully developed, and which is therefore exceedingly well-suited for investigation.

The chlorophyll-globules of the second kind are frequently larger than those above described; their diameter amounts, for example in the leaf of *Ceratophyllum demersum*, to $\frac{1}{120}$ of a line. In their interior may be perceived, even in the fresh globules, more distinctly however after the action of water, and still more clearly by the blue colour produced by iodine, one or more starch-grains, which not unfrequently are of such size that the green substance forms only a thin coat over them; in many cases, however, the starch forms only a subordinate part of the entire globule, appearing under the form of one or more small nuclei, the diameter of which is only one-half or one-third that of the chlorophyll-globule. The surface of the entire chlorophyll-globule is smoother than in many of the first kind; the green substance ordinarily with finer granules.

The action of water upon these globules is often exceedingly slight, frequently quite imperceptible after a continuance of twenty-four hours. Speaking generally, it is limited to rendering the outlines of the starch-granules more clearly visible, which seems to arise from a little water making its way between the starch-granule and the green substance which forms an envelope around it. The latter remains quite unaltered. When a portion of it is accidentally removed from the starch-grain in making the sections, or when the latter is caused to swell up by the application of an acid, so that the green coat is broken through and stripped off, it may be perceived that the green substance possesses sufficient solidity to preserve its original shape and the cavity in which the starch-grain lay; it is however soft enough to allow of being thrown into coarse folds by lateral pressure. Under these circumstances it presents the characters of a gelatinous mass not swelling perceptibly in water, and, so far as can be seen, coloured green throughout its entire thickness. I never saw vacuoles formed in it. Among the plants I have examined, the internal cells of the leaves of *Ceratophyllum demersum* are best adapted for the investigation of this form of the chlorophyll-globules.

I have remarked above that these two forms of chlorophyll-globule very often pass into one another, but it must be noted in regard to this, that divers forms never occur in the *same* cell, although in different cells of the same plant. For example, it is extremely common to meet with chlorophyll-globules belonging to the first kind in form and size, but containing in their interior one or more grains of starch. In proportion to the diminishing size of these starch-grains (and they are often so small

that they can only be recognized as such by the help of iodine after they have been expanded by boiling), the chlorophyll-globules approach nearer to the above-described first variety, devoid of starch, while on the contrary, others in which the starch-grains are larger form the transition to the above-described globules of *Ceratophyllum*. These intermediate forms behave differently with water, being sometimes wholly insensible to it (as for instance, the chlorophyll-globules of *Vallisneria, Potamogeton crispus,* and the central substance of the leaf of *Hoya carnosa*), sometimes swelling out into vesicles in water (*e. g.* those contained in the leaf of *Bromelia Ananas*), under which circumstances the not infrequent isolated starch-grains lie free in the water filling the vacuoles, and exhibit molecular motion.

With regard to the distribution of the two forms of chlorophyll in different cells of the same plant, a general rule exists. In the outer layers of cells, both of bark and of the two faces of leaves, occur globules containing no starch, or others with starch-grains only of exceedingly small size, and ordinarily, like the former, swelling up vesicularly in water. In the layers of the bark bordering on the wood, and in the middle layers of leaves, on the other hand, occur globules possessing comparatively large starch-grains, better resisting the action of water. However, we do not find both kinds of globule in every leaf; there are plants in which all the layers of the leaf, even the middle, contain only chlorophyll-globules without starch. It will not be superfluous to name certain plants in which the diversities just noticed may be recognized.

Chlorophyll-globules without starch occur in all the layers of the leaves of *Elymus arenarius, Iris germanica, Scilla maritima, Tulipa Gesneriana, Phormium tenax, Yucca gloriosa, Clivia nobilis, Menyanthes trifoliata, Ilex Aquifolium, Aralia trifoliata, Sedum Telephium, Cochlearia officinalis.*

Leaves where the outer layers contain chlorophyll-globules without starch, while in those forming the middle substance of the leaf, starch occurs, are found in *Acrostichum alcicorne, Stratiotes aloides, Potamogeton crispus, Piper magnoliæfolium, Camellia japonica.*

Leaves in which all the chlorophyll-globules contain starch, where however those in the outer layers of cells approximate to those devoid of starch, while those situated in the middle of the leaf contain large starch-grains, occur in *Billbergia zebrina, Bromelia Ananas, Vallisneria spiralis, Viscum album, Ceratophyllum demersum, Hoya carnosa.*

In regard to the preceding enumeration, it must be observed that the statement, whether the starch exists or not in the chlorophyll-globules, refers only to the fully-developed leaf, and not to